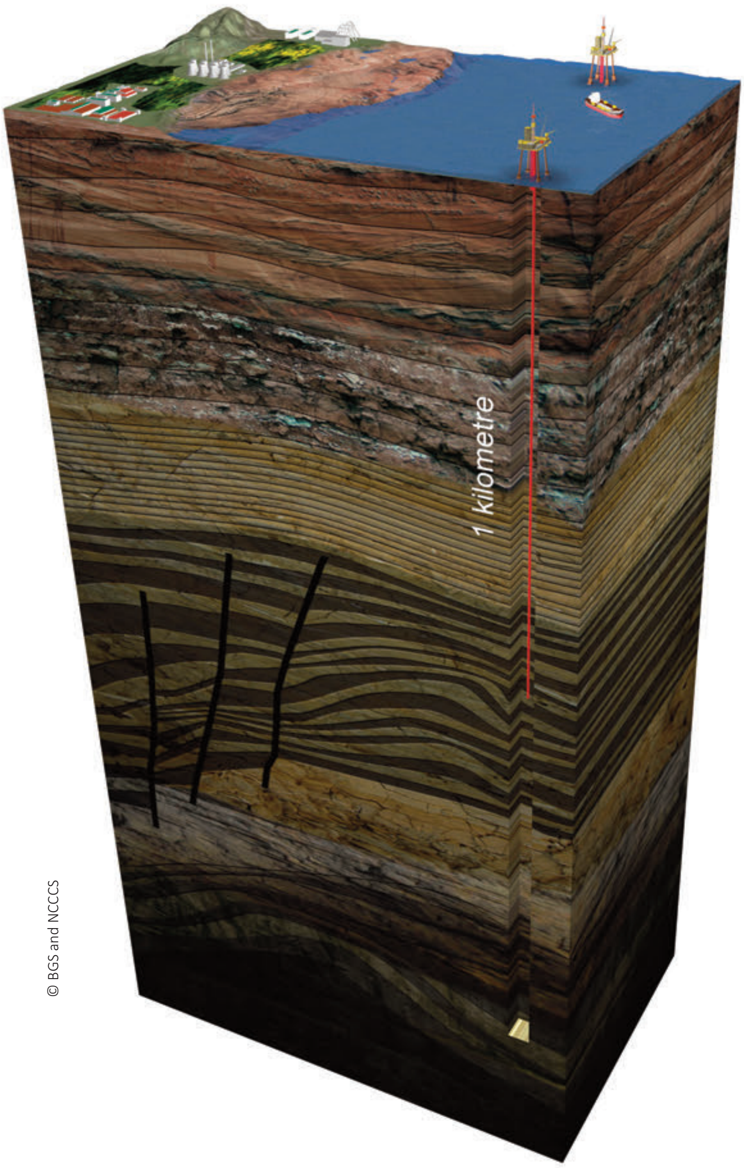
Reducing carbon dioxide emissions

by storing CO_2 deep underground

CO_2GeoNet

The European Network of Excellence on the Geological Storage of CO_2

www.co2geonet.eu



Geological storage site with depth to scale

CO_2 Geological Storage: a key technology for reducing CO_2 emissions

What is CO_2 Capture and Storage?

CO_2 Capture and Storage (CCS) involves the capture of carbon dioxide (CO_2) from industrial sources such as fossil-fuel-based power stations, refineries, steel or cement plants followed by compression of this CO_2 into a highly dense liquid form, and its injection deep underground into the pore space (i.e. the voids between the rock grains) of reservoir rocks in depleted oil and gas fields or saline aquifers. Four trapping mechanisms contain the CO_2:

- Structural trapping is the main short-term mechanism, whereby overlying impermeable layers of 'cap rock' act as a seal, effectively trapping the CO_2 in the porous reservoir rock.

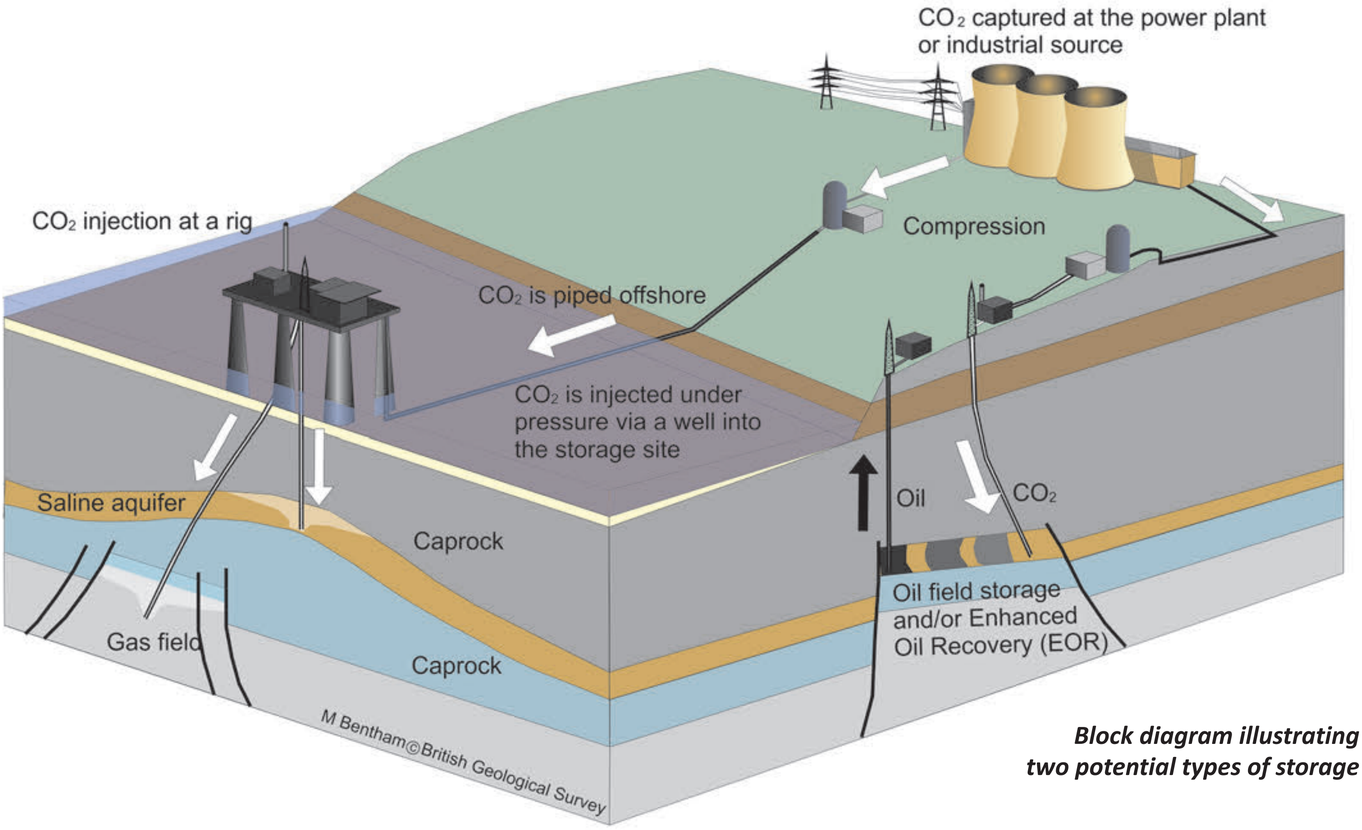
Over longer timescales, three other natural trapping processes occur, further increasing the security of CO_2 storage over time:

- Residual trapping; some of the CO_2 is left behind as it moves through the pore spaces of the rocks. These small pockets of CO_2 then cannot move, even under pressure.

- Dissolution trapping; a portion of the CO_2 dissolves into the water in the rock pores forming a dense fluid which then sinks.

- Mineral trapping; the CO_2-rich water may slowly react over time to form solid carbonate minerals, thereby providing a permanent form of storage.

A comprehensive description of CO_2 Geological Storage can be found in the CO_2GeoNet brochure "What does CO_2 Geological Storage really mean?" available in 27 languages from the CO_2GeoNet website.



Block diagram illustrating two potential types of storage

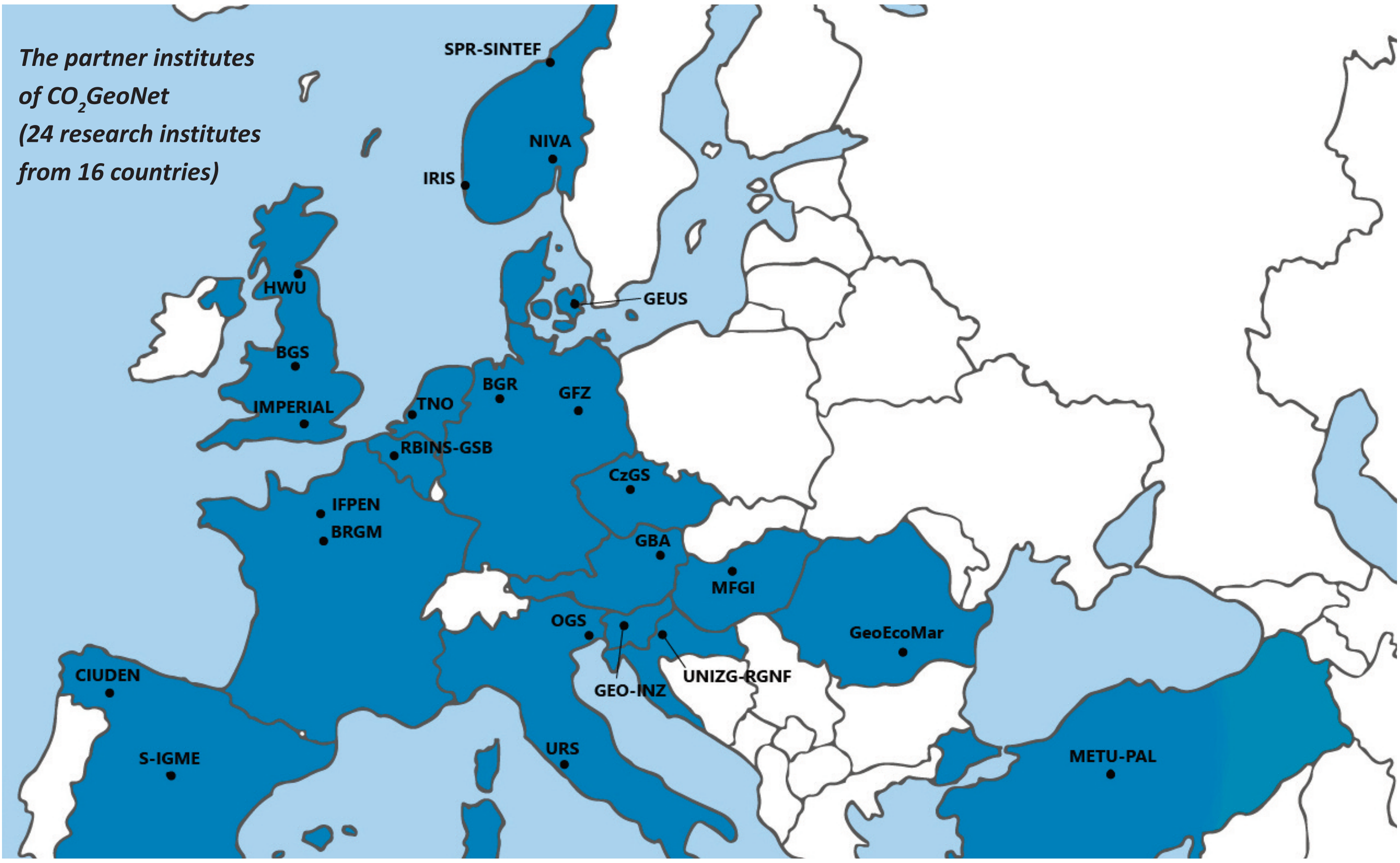
Why do we need Geological Storage of CO_2?

CCS is the only technology that can greatly reduce CO_2 emissions from fossil fuel-fired power stations and other industrial sources, such as cement and steel plants. From the 1990s onwards, CCS has been seriously considered and studied as an essential method of reducing CO_2 emissions to the atmosphere, by which carbon extracted from underground in the form of gas, oil and coal is returned to the deep subsurface in the form of CO_2.

Prolific burning of fossil fuels for power production, heating, industry and transportation began at the start of the Industrial Age in the 1750s and now accounts for 80% of anthropogenic CO_2 emissions into the atmosphere. There is very high confidence that this is directly linked to global warming. Currently, 80% of the energy we use comes from fossil fuels and the transformation of our society into a low carbon economy based on a diverse mix of energy sources will take time. CO_2 capture and storage is a potential bridging technology towards this low carbon economy. This change needs to take place soon in order to mitigate greenhouse gas (GHG) emissions and avoid the worst effects of climate change.

Where CCS is applied to bio-energy plants it can even lead to negative CO_2 emissions; the growing biomass removes CO_2 from the atmosphere and when this biomass is used as fuel in a plant with CCS, this CO_2 is then captured and permanently stored.

Large-scale CO_2 storage is particularly appropriate in Europe because of the combination of a large number of industrial and power plants producing CO_2 emissions and the presence of favourable geology for storage. The European Strategic Energy Technology (SET) Plan roadmap on low carbon energy technologies built a vision for the European energy system such that by 2020 the transition to a low carbon economy should be well underway. Aditionally, the International Energy Agency has stated that CCS can and should contribute 20% of the CO_2 reduction needed by 2050 in order to achieve stabilisation of atmospheric GHG concentrations in the most cost-effective manner. Clearly, the World is behind schedule and a step-change in activity and research is required to achieve this. The IEA has proposed a



scenario of progressive implementation leading to over 30 CCS projects in operation by 2020 and CCS being used routinely to reduce emissions from all applicable sources by 2050 with over 7 Gt (Giga tonnes) of CO_2 stored per year.

Is CO_2 Geological Storage viable?

All storage sites to date, both the pioneer large-scale industrial CCS operations, e.g. Sleipner (Norway), Weyburn (Canada), In Salah (Algeria), Snohvit (Norway), and the small-scale CO_2 injection pilots e.g. K12-B (The Netherlands), Frio (USA), Nagaoka (Japan), Ketzin (Germany), Otway (Australia), Lacq-Rousse (France) demonstrate CCS as a feasible technology.

There are seven large-scale installations currently operating world-wide that individually store greater than 0.68 Mt CO_2 p.a. (per annum), with a total of 22 Mt p.a. collectively (Global CCS Institute). 1.7 Mt p.a. are stored by two large-scale industrial projects specifically designed for CCS (Sleipner and Snohvit) and the remaining 20.38 Mt p.a. are stored through five Enhanced Oil Recovery (EOR) schemes that utilise anthropogenic CO_2 injection (Weyburn, USA/Canada, Val Verde, USA, Enid Fertiliser Plant, USA, Shute Creek gas processing facility, USA, Century Plant, USA). Two further projects in the USA, each with a planned injection rate of 1 Mt p.a., began to inject CO_2 in 2013 (Air products methane reformer is providing CO_2 for EOR and the Illinois Basin, Decatur Project is storing CO_2 in a saline aquifer formation).

Current estimates of total global capacity suggest that up to 11,000 Gt can be stored (IEA Greenhouse Gas R&D Programme), 90% of which is in deep saline aquifers and 10% in depleted oil and gas fields. Based on current estimates, availability of sufficient pore space would not appear to be an issue. However, these assessments are largely based on broad regional studies and need to be refined. The total useable storage capacity of each site, achievable CO_2 injection rate and confirmation of local seal integrity will require more detailed research.

The suitability of a site is not only determined by its geological characteristics; regulatory and economic factors also impact on the feasibility of CCS at different locations. In Europe, the EU Directive 2009/31/EC on the geological storage of carbon dioxide supports CCS from a regulatory perspective and has been transposed in many member states to permit CCS in-country. CCS was also supported by the European Parliament resolution of 14 January 2014, 2013/2079(INI), adoption of implementation report 2013: Developing and applying carbon capture and storage technology in Europe.

Progress towards full-scale implementation of CCS technology requires the development of financial incentives (which could include carbon tax, performance standards, higher carbon credit prices, cap and trade, feed in tariff, etc). It is also increasingly recognised that no investment decisions can be taken for CCS projects without confidence being established early on in the process regarding the storage sites in terms of capacity, efficiency and safety.

The EU commission is trying to support early demonstration projects through the NER300 Scheme which is designed to subsidise the demonstration of clean energy projects innovative renewable and CCS installations (NER300 is a financing instrument managed jointly by the European Commission, European Investment Bank and Member States funded through the sale of 300 million emission allowances from the new entrants' reserve (NER) in two phases in order to subsidise innovative renewable and CCS installations).

Currently the main scheme offering commercial credit for reducing emissions in Europe is the EU Emissions Trading Scheme (ETS) whereby companies are granted or purchase a number of credits for their CO_2 emissions. Companies with lower emissions have the opportunity to sell carbon credits to other companies in order to reduce their running costs. However, in combination with the downturn of economic and industrial activities in Europe, this market has plummeted due to a surplus of quotas. With low CO_2 unit values, the ETS alone will not fund early demonstration projects, other support mechanisms are required.

Is CO_2 Geological Storage safe?

Safety is an essential consideration for any site. On the basis of all current research, including experience from existing storage sites, geological storage of CO_2 is viewed as a viable and safe technology. Confidence in a specific site can only be assured through extensive research involving detailed characterisation, deployment of appropriate monitoring techniques and modelling of the storage reservoir, cap rock and surrounding areas to confirm that the site is evolving as expected. Major co-operative research programmes on CCS, the first of which dates back to 1993, continue to be undertaken with the aim of thoroughly understanding the natural systems into which CO_2 will be injected and the potential risks they could present for CO_2 storage. Such studies have led to the formulation of best practice recommendations. Sites will not be developed if safety issues cannot be resolved.

The key safety concern is the potential for CO_2 to migrate out of the storage site or leak to the surface. Detailed characterisation of the storage site is required to confirm the ability of the sealing cap rock to trap the CO_2 over long timescales. Integrity of the seal depends on thickness, low vertical permeability and lack of migration pathways (e.g. fractures) as well as the type and rate of chemical reactions with the CO_2. Geochemical integrity of the seal is ensured through thorough site characterisation prior to injection. Mechanical (physical) cap rock strength needs to be established through a combination of experimental testing and modelling during site characterisation. Monitoring is required during CO_2 injection to ensure that seal integrity is maintained and the injection rate will be controlled to ensure that the seal is not breached.

For large scale storage, it must be possible to inject CO_2 at a sufficient rate into this pore space without compromising the reservoir rock or the seal integrity. The safe rate of injection and number of wells required depends on the nature of the proposed reservoir and seal rocks. In depleted oil and gas fields where the pressure of the reservoir has been lowered by hydrocarbon extraction, or in extensive saline aquifers with well connected pore spaces, keeping reservoir pressure below acceptable limits is not likely to be a significant issue. Where modelling suggests that pressure build-up is likely to be an issue, more advanced engineering solutions, such as those based on well configurations, will need to be considered.

The potential for inducing seismicity (ground movement) has also been raised. Injection activities worldwide related to oil and gas, geothermal, waste disposal and storage operations are not usually linked to the triggering of large-scale earthquakes which could result in a breach of cap rock integrity or damage at the surface. Furthermore, hydrocarbon accumulations are found in highly seismically active geological provinces demonstrating that natural seals can resist even large-scale earthquakes.

A useful comparison can be drawn with natural subsurface CO_2 accumulations which demonstrate secure storage of buoyant fluids over periods of millions of years. In addition, studies on natural seeps have demonstrated that CO_2 leaks would not necessarily represent a major safety hazard, as the spatial impact on the near-surface environment is limited and CO_2 usually disperses into the atmosphere. Many insights into geological storage security have also been gained from studies of CO_2 injection for Enhanced Oil Recovery and seasonal natural gas (CH_4) storage which have been undertaken since the 1970s.

Regulations control risk management for CCS and this important role is now being fulfilled by specific European and national legislation. The EU Directive 2009/31/EC on the geological storage of carbon dioxide, and its national transposition by member states, requires rigorous characterisation and understanding of proposed storage reservoir and caprock, including assessment of expected long-term evolution of the site and a risk assessment which demonstrates that the selected site has no significant risk of leakage and no significant environmental or health risks. No site will be accorded a storage permit that cannot demonstrate minimal, acceptable and manageable risks. During the injection period, site performance will also be carefully monitored to allow refinement of long-term post-injection performance predictions, with the intention of further increasing confidence that individual sites will not allow CO_2 to escape. Contingency plans must be in place to respond to any significant irregularities including unexpected leakage, should they arise. As an example, injection at In Salah is currently suspended while the latest caprock and reservoir data are reviewed to more fully understand the response to the injected CO_2.

Can CO_2 Geological Storage be implemented quickly enough?

CCS can be implemented in time to avoid the worst effects of climate change but the longer large-scale implementation is delayed, the more expensive and more challenging it will be to implement CCS quickly enough.

Both small-scale pilots and demonstrations at commercial scale are needed to drive CCS forward. Demonstrations will prove safe and secure storage at scale. Small scale pilot projects will allow testing of a range of geological storage types and novel concepts with regards to injection strategies and monitoring technologies at lower costs. Pilot projects will also provide benefits to investment decisions through increased confidence in storage sites, including identifying more potential locations and improving capacity estimates, technical efficiency and safety. There is still scope for CCS development (as with other technologies), particularly to gain experience in different settings, to optimize processes and for larger scale deployment of CCS.

Geological storage is the key issue that needs to be addressed at a potential site before any other aspect, such as transport infrastructure and CO_2 capture schemes are considered in detail. Unlike the capture or transport processes that can be implemented throughout the world once fully tested, the storage process is site dependent. Each storage site is unique due to its (often unexplored) local geology and its ability to trap CO_2 over periods of thousands of years must be demonstrated on a site by site basis. Assessing a storage site is a long and detailed process, involving man-years of technical input over a period of many months to years. Baseline data collected prior to injection are essential for comparison with data obtained during the storage operations. There is therefore an urgent need to start this process of geological characterisation of each specific site as early as possible.

The failure of the first phase of the NER300 scheme to fund any CCS demonstrations (as the projects were not judged to be sufficiently advanced or funding gaps were present; ec.europa.eu website), has led to the acknowledgment that the original target of up to 12 CCS demonstrations by 2015 in

Europe is no longer realistic. The need for GHG emission reductions remains urgent and therefore the requirement for CCS schemes to be demonstrated at full scale is even more pressing. Thus, additional funding mechanisms need to be identified in order for CCS to enter the next essential developmental phase with a greater number of operating demonstration projects and more research projects studying a wider range of storage options. In the meantime, options such as small scale pilot projects may provide an alternative or transitional focus to maintain momentum and further develop scientific and engineering knowledge and to enhance practical skills.

CO_2 Geological Storage research in Europe

Europe can claim the largest integrated scientific community in the field of Geological Storage of CO_2. The CO_2GeoNet Association is the European Network of Excellence on this topic. It has a large and growing membership of research organisations across Europe that covers all areas of expertise relevant to CO_2 storage and is at the forefront of research. With activities encompassing joint research, training, scientific advice, information and communication, CO_2GeoNet has a valuable role to play in enabling the efficient and safe geological storage of CO_2.

CO_2GeoNet believes that the necessary acceleration of CCS development and deployment requires an increase in the number of pilot projects and demonstrations as well as the number of research activities on CO_2 storage, for a range of site-specific, regional, and generic issues.

Research topics requiring focus in the short term include more accurate definition and mapping of storage capacity, improving and integrating different aspects of modeling, pressure management and injection strategies for saline aquifers, improved knowledge on fault behaviour, impact of geological heterogeneities, impact of CO_2 impurities resulting from the capture process, improved and innovative monitoring techniques and strategies (higher resolution, real-time, cheaper, able to monitor changes due to physical and chemical processes, at any depth and at any time), mitigation and remediation techniques and strategies and interactions with other uses of the subsurface (e.g. geothermal energy, hydrocarbon reservoirs, water resources).

CCS research requires strong international cooperation and knowledge sharing, particularly in the field of geological storage since the knowledge gained from each pilot project or demonstration is valuable and builds understanding and confidence. CO_2GeoNet aims to be pivotal in this role, providing independent advice and opportunities for the exchange of ideas and knowledge such as the annual CO_2GeoNet Open Forum and encouraging co-working and pooling of expertise across the whole of Europe.

For more information on CO_2 Geological Storage, please see our website: **www.co2geonet.eu**

CO_2GeoNet and CGS Europe project partners at a natural gas storage site in Slovakia

The road to carbon reduction

European Commissioner for Energy, Günther H. Oettinger details his proposals for the Energy Roadmap 2050 and how it will influence Europe's energy strategy…

Energy is one of the biggest challenges Europe is confronted with today. While being at the helm of the fight against climate change, our economic competitiveness fully depends on a reliable energy supply at an affordable price. And in turn, this depends on adequate infrastructure. Until the end of the 1990s, boosting demand was more important than energy efficiency and energy suppliers primarily served national markets. From now on, energy systems need to be designed to run on variable renewable and low-carbon fuels at continental level. Is Europe ready and able to take up the challenge? Will Europe be able to reduce greenhouse gas emissions by at least 80% by 2050 and maintain competitiveness? The European Commission launched the debate with the publication of the Energy Roadmap 2050.

What does the Energy Roadmap 2050 say?

Through an analysis based on scenarios, the Roadmap 2050 indicates possible pathways to achieve the decarbonisation of the EU energy system. The purpose is not of choosing one over another, rather of identifying the common emerging elements that support long-term approaches to investments. The real world will never look like these models, but the conclusions drawn from them give fundamental signals for our future policy.

The main conclusion of the Roadmap is simple: transformation of the energy system is technically and economically feasible – if we make the right choices.

Five key lessons can guide us in making the policy choices to shift our energy system towards a more sustainable future.

(1) Energy savings are crucial

There is a vast amount of untapped potential to save energy. Significant energy savings would need to be achieved in all decarbonisation scenarios. Primary energy demand drops in a range of 16% to 20% by 2030 and 32% to 41% by 2050, as compared to peaks in 2005-2006. Thus, energy efficiency is crucial for the energy system transformation – at the stages of production, supply and end use. To this end, the EU has adopted a new energy efficiency directive which obliges Member States to implement binding measures such as an obligation scheme for energy companies to cut down energy consumption at customer level, and an obligation for Member States to renovate annually 3% of the central government's building. It also encourages energy audits for SMEs and an obligation for large companies to assess their energy saving possibilities.

But we must be more ambitious. In the long-run, higher energy efficiency in new and existing buildings is crucial. Nearly zero energy buildings should become the norm. Products and appliances should fulfil the highest energy efficiency standards. In transport, efficient vehicles and incentives for behavioural change are needed. All this requires more action both at EU and Member State level.

(2) The share of renewables rises substantially

The analysis shows that the biggest share of energy supply technologies in 2050 comes from renewables. In 2030, all de-carbonisation scenarios suggest growing shares of renewables of around 30% in gross final energy consumption. In 2050, renewables will achieve at least 55%, up 45 percentage points from today's level. This is both a huge change and a challenge. Renewables will play a central role in Europe's energy mix, from technology development to mass production and deployment, from small-scale to large-scale, from subsidised to competitive. All these shifts require parallel changes in policy. Incentives in the future have to become more efficient, create economies of scale, and lead to more market integration.

(3) Building the necessary infrastructure is key

With electricity trade and renewables' penetration growing up to 2050 under almost any scenario, adequate infrastructure at distribution, interconnection, and long-distance transmission levels becomes a matter of urgency. The existence of adequate infrastructure is a condition sine qua non. In the long-run, the extension of the current planning methods to a fully integrated network planning for transmission, distribution, storage and electricity highways looking at a potentially longer timeframe will be needed. And above all, we need to develop more intelligent electricity grids, able to deal with variable generation from many distributed sources, allowing for new ways to manage electricity demand and supply.

(4) The European energy markets needs to be fully integrated

A European market offers the right scale to assure access to resources and to provide the huge investments needed. The single energy market must be fully integrated by 2014. An additional challenge is the need for flexible resources in the power system, as there will be more variable renewables. Access to flexible supplies of all types (e.g. demand management, storage and flexible back-up power plants) has to be ensured. Another challenge is the impact of renewable generation on the wholesale market prices. Whatever the answer, it is important that market arrangements offer cost-effective solutions to these challenges. The cross-border impact on the internal market deserves renewed attention. Now more than ever, coordination is required. Energy policy developments need to take full account of how each national system is affected by decisions in neighbouring countries.

(5) Investing in low-carbon technologies

Carbon pricing can provide an incentive for deployment of efficient, low-carbon technologies across Europe. The ETS is a necessary condition for the energy system transformation, but it is not sufficient. Higher public and private investments in R&D and technological innovation are also crucial in speeding-up the commercialisation and the modernisation of all low-carbon solutions, whatever the sources are. In particular, Europe will certainly have to develop further Carbon Capture and Storage (CCS) from around 2030 onwards in the power sector in order to reach the decarbonisation targets.

New opportunities for Europe

Indeed, it is cheaper and easier for Europe to work together. The European market gives us the chance to make economies of scale and speed up new markets for low-carbon technologies. Between now and 2050, there must be a wide-scale replacement of infrastructure and appliances throughout the economy, including consumer goods in people's homes. Modernising the energy system will bring high levels of investment into the European economy. It can bring more jobs, more quality of life, and more growth. Decarbonisation can also be an advantage for Europe, placing itself as an early mover in the growing global market for energy-related goods and services. Energy system transformation also helps to reduce import dependency and exposure to the volatility of fossil fuel prices.

The Way forward

At EU level, we had set ourselves three targets for 2020 – a 20% share of energy from renewable sources, a 20% increase in energy efficiency and a 20% cut in CO_2 emissions compared to 1990 levels. Now, in 2013 we must look beyond this date and reflect what should happen in 2030. This is why we launched a consultation before coming forward with concrete proposals. We have to decide which climate and energy targets will be set, whether they are technology-specific, mandating a certain proportion of renewables for example, or if they shall be general emissions targets requiring Member States to curb their CO_2 output using the technology they prefer. We must soon decide on the 2030 framework to allow Member States to prepare and to give certainty to investors in industry – because for investors, 2030 is already tomorrow.

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CO_2GeoNet: The European Network of Excellence on the Geological Storage of CO_2

CO_2GeoNet is a non-profit Scientific Association which comprises a large and growing independent group of leading research institutions in the field of CO_2 storage, unmatched anywhere else in the World. CO_2GeoNet is the only integrated scientific community with comprehensive multidisciplinary expertise, focused on CO_2 storage that is independent of political, industrial or societal pressures. With activities encompassing joint research, training, scientific advice, information and communication, CO_2GeoNet has a valuable and independent role to play in enabling the efficient and safe geological storage of CO_2. CO_2GeoNet was created in 2004 as a Network of Excellence under the EC 6th Framework which lasted for 5 years. In 2008, the Network became a non-profit Association under French law. The CO_2GeoNet Network of Excellence has recently expanded as partners from the now completed CGS Europe project became members. CO_2GeoNet now comprises 24 partners from 16 European countries and involves more than 300 researchers with the multidisciplinary expertise needed to address every facet of CO_2 geological storage.

www.co2geonet.eu

Founding members of CO_2GeoNet:

GEUS, Denmark –	Geological Survey of Denmark and Greenland;
BRGM, France –	Bureau de Recherches Geologiques et Minieres;
IFPEN, France –	IFP Energies Nouvelles;
BGR, Germany –	Bundesanstalt für Geowissenschaften und Rohstoffe;
OGS, Italy –	National Institute of Oceanography and Experimental Geophysics;
URS, Italy –	Universita di Roma "La Sapienza";
TNO, The Netherlands –	Netherlands Organisation for Applied Scientific Research;
IRIS, Norway –	International Research Institute of Stavanger;
NIVA, Norway –	Norwegian Institute for Water Research;
SPR, Norway –	SINTEF Petroleum Research;
BGS, UK –	British Geological Survey;
HWU, UK –	Heriot-Watt University;
IMPERIAL, UK –	Department of Earth Science and Engineering, Imperial College London.

New members of CO_2GeoNet:

GBA, Austria –	Geologische Bundesanstalt;
RBINS-GSB, Belgium –	Royal Belgian Institute of Natural Sciences;
UNIZG-RGNF, Croatia –	University of Zagreb – Faculty of Mining, Geology and Petroleum Engineering;
CGS, Czech Republic –	Czech Geological Survey;
GFZ, Germany –	Helmholtz Centre Potsdam, German Research Centre for Geosciences/Deutsches GeoForschungsZentrum;
MFGI, Hungary –	Magyar Földtani és Geofizikai Intézet;
GeoEcoMar, Romania –	National Institute of Marine Geology and Geoecology;
GEO-INZ, Slovenia –	Geoinženiring d.o.o.;
CIUDEN, Spain –	Fundación Ciudad de la Energîa;
S-IGME, Spain –	Instituto Geológico y Minero de España;
METU-PAL, Turkey –	Middle East Technical University Petroleum Research Center.